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Investigations on the forces during hard turning of AISI52100 steel

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ABSTRACT

Turning of hardened steels using single-point cutting tool has got considerable interest as it acquires many benefits like lower equipment costs, shorter setup time and fewer process steps which in turn provides high flexibility and ability to cut complex geometries over traditional grinding. The potential of hard turning to eliminate the costs associated with additional finishing processes in conventional machining is appealing to industry. The idiosyncratic process conditions of turning of hardened materials warrant specific treatment in the parametric analysis. The present work is aimed to investigate the forces generated and roughness of the obtained surface during the turning of hardened AISI52100 alloy steel under various operating conditions namely speed, feed, depth of cut and nose radius. The machine used for hard turning is Centre lathe with variable speed & feed drive. The cutting tool inserts used are poly crystalline cubic boron nitride (PCBN) CNMG 120404, CNMG 120408 and CNMG120412. Cutting forces are taken for each experiment by using KISTLER multi component dynamometer and one more output response is surface roughness of material in each experiment is obtained with MITUTOYO make surface roughness tester. Experiments are devised using Taguchi L27 orthogonal array and the influence of the input parameters on the forces and roughness is predicted with S/N ratio analysis. The results indicated that speed and depth of cut are dominant factors for feed force. Nose radius and depth of cut are significant effect on thrust force. The depth of cut and feed affect significantly on tangential force. Surface roughness is found to be affected significantly by nose radius and Depth of cut.

Keywords: hard turning, Taguchi technique, S/N ratio

1. INTRODUCTION

Turning of hard steels (above 45 HRC) termed as hard turning, and it is proved to be the possible alternative for grinding as the lead times were reduced due to less setups recommended without compromising surface quality. As the tool in turning was to be harder than work piece, hence the main tool materials that are used for hard turning include sintered carbides, ceramics (e.g. Al_2O_3 or Si_3N_4 etc.), and extra-hard materials (e.g. PCD, PCBN etc.). In general, turning process is strongly affected by the forces generated with respect to the tool geometry and surface quality (shaw, 1984). Significant development of cutting forces were observed during hard turning (Tonshoff and Chryssolouris (1981)Konig et al. (1984)). Koenig et al. (1984) found that cutting force was 50% larger and feed and thrust forces were 100% larger when turning a 100CrMo7 ball bearing steel of hardness 63 HRC as compared to turning the same material having hardness 32 HRC. Panzera et al (2012) investigated the effect of the cutting parameters (cutting speed, feed rate, and depth of cut) on the cutting force components during dry turning AISI 4340 steel using coated carbide inserts. The results of their study indicated that the three components of the turning force decrease slightly as cutting speed increases and also they increase linearly with feed rate and depth of cut. Aouici et al (2010) studied the influence of the cutting parameters (cutting speed, feed rate, and depth of cut) on cutting force components during turning of AISI H11 steel treated at 50 HRC using CBN tool (57% CBN and 35% Ti(C, N)). Their results indicated that (i) tangential cutting force is very sensitive to the variation in cutting depth, (ii) thrust force is dominating compared to both others cutting forces. Lee (2011) developed a theoretical model to predict cutting forces for machining AISI 4140-hardened materials (45HRC) that contain more than 0.58% carbon. His predicted values of cutting forces from the model were found to be in good agreement with those measured from an experiment of hard machining of AISI 4140 steel heat-treated. Arsecularatne et al. (2006) studied the machining of AISI D2 steel (62 HRC) with PCBN tools using three levels of speed and feed rate for studying tool life and cutting forces. They found that the relation between forces and cutting conditions (speeds and feeds for a constant depth of cut) was represented by power function-type equations (force $=A\times Va1\ \times fa2$, where A, $a1$, $a2$ are constants). Further, they stated that 70m/min speed is more suitable in machining selected tool/work material combination for highest acceptable value of tool life and volume of material removal. Many studies emphasized the effect of speed, feed and depth of cut on forces during hard turning, little emphasize was made on the effect of nose radius. Hence the present work aims to investigate the effect of nose radius on various forces generated during turning of hardened steels apart from the speed, feed and depth of cut.

2. EXPERIMENTAL PROCEDURE

2.1. Material and Machine Tool

The work material is AISI52100 alloy steel which has its major application in bearings. Bars of AISI52100 steel, 32mm in diameter and 350mm in length are used in this study. The hardness after heat treatment is obtained as 58.0±0.5 HRC. The cutting inserts used are PCBN tool inserts of different nose radius 0.4, 0.8, 1.2 mm (CNMG 120404, CNMG 120408, and CNMG 120412). Rigid, high power precision lathe equipped with specially designed experimental setup was used for experimentation. For increasing rigidity of machining system, workpiece material is held between chuck (three jaws) and tailstock (revolving center) and the turning of work piece in dry turning conditions are conducted on "centre lathe with variable speed & feed drive (Make: kirloskar; Model: turnmaster-35)". The cutting forces are measured using Kistler® multi component dynamometer (type: 9257B) mounted on specially designed fixture. The charge generated at the dynamometer was amplified using three-charge amplifier (charge amplifier: 5070A). The input sensitivities of the three-charge amplifiers were set corresponding to the output sensitivity of the force dynamometer in the *x*, *y* and *z* directions. The outputs are tangential force (Fz), feed force (Fx) and thrust force (Fy) on the respective charge amplifier generated and stored in computer using Lab VIEW software for further analysis.

Table 1 Ranges of cutting parameters

Cutting parameter	Units	Level 1	Level 2	Level 3
Cutting speed	rev/min	400	650	900
Feed rate	mm/rev	0.04	0.06	0.08
Depth of cut	mm	0.4	0.6	0.8
Tool nose radius	mm	0.4	0.8	1.2

2.2. Experimental Details

Lin and Chen (1995) studied cutting forces and surface roughness as function of cutting speed (44.5, 83, 144.5 m/min), feed rate (0.039, 0.104, 0.210, 0.216mm/rev) and depth of cut (0.2mm) for 64 HRC hardened bearing steel. Chen (2000) also, studied the cutting forces and surface roughness for 45–55 HRC steel using CBN tool for the cutting speed (56–182 m/min), feed rate (0.08–0.31mm/rev) and depth of cut (0.025–0.1 mm). Based on (Lin and Chen, 1995; Chen, 2000) and tool manufacturer recommendations, feasible range of cutting parameters for a given cutting tool–work piece system were selected as follows (Table 1).

2.3. Experimental procedure

Total 27 experiments were done according to L27 orthogonal array. The cutting forces are obtained by using KISTLER multi component dynamometer arrangement, with this dynamometer tangential force (Fz), feed force (Fx) and thrust force (Fy) are measured and tabulated.

Table 2 design matrix with responses

S.NO	Speed, rpm	Feed mm/rev	depth of cut mm	Nose radius mm	F_X(N)	F_Y(N)	F_Z(N)
1	400	0.04	0.4	04	286.2e0	142.0e0	285.4e0
2	400	0.06	0.6	08	94.35e0	172.5e0	131.7e0
3	400	0.08	0.8	12	267.5e0	509.7e0	362.9e0
4	400	0.04	0.6	12	146.5e0	322.8e0	147.4e0
5	400	0.06	0.8	04	180.6e0	116.7e0	243.3e0
6	400	0.08	0.4	08	310.2e0	267.8e0	409.9e0
7	400	0.04	0.8	08	263.9e0	358.4e0	366.3e0
8	400	0.06	0.4	12	319.5e0	522.4e0	353.4e0
9	400	0.08	0.6	04	103.1e0	107.3e0	129.8e0
10	650	0.04	0.4	04	233.6e0	128.7e0	211.3e0
11	650	0.06	0.6	08	78.37e0	157.6e0	126.5e0
12	650	0.08	0.8	12	280.7e0	482.5e0	372.3e0
13	650	0.04	0.6	12	112.5e0	301.3e0	101.2e0
14	650	0.06	0.8	04	1.293e3	489.6e0	530.6e0
15	650	0.08	0.4	08	301.8e0	265.0e0	394.1e0
16	650	0.04	0.8	08	231.5e0	249.1e0	254.0e0
17	650	0.06	0.4	12	281.5e0	411.2e0	304.1e0
18	650	0.08	0.6	04	77.55e0	117.1e0	118.6e0
19	900	0.04	0.4	04	212.8e0	118.0e0	211.5e0
20	900	0.06	0.6	08	66.33e0	146.2e0	101.5e0
21	900	0.08	0.8	12	257.4e0	498.0e0	349.0e0
22	900	0.04	0.6	12	105.2e0	236.6e0	86.06e0
23	900	0.06	0.8	04	192.3e0	138.1e0	262.8e0
24	900	0.08	0.4	08	284.5e0	276.8e0	370.2e0
25	900	0.04	0.8	08	218.9e0	198.6e0	205.5e0
26	900	0.06	0.4	12	264.7e0	510.0e0	319.0e0
27	900	0.08	0.6	04	74.39e0	92.29e0	129.9e0

3. RESULTS AND DISCUSSIONS

The effect of various cutting parameters on forces is established with S/N ratio analysis.

3.1. Main effects plot for F_X

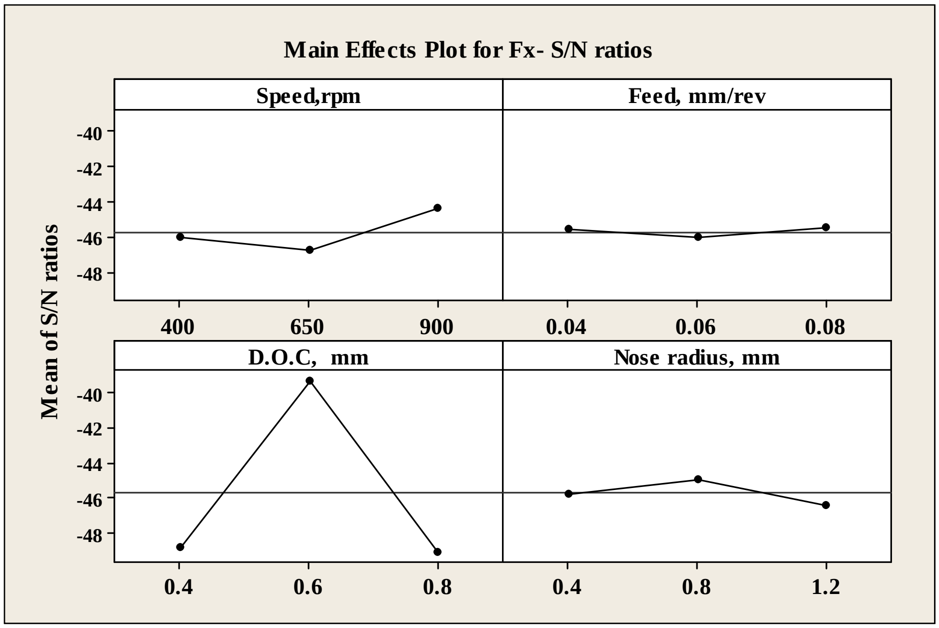

Figure 1 main effects plot for F_X – S/N ratios

From these four graphs the slope of depth of cut vs. mean of S/N ratio graph is largest, speed vs. mean of S/N ratio graph possesses second largest slope so feed force (Fx) is significantly affected by depth of cut and speed but feed, nose radius has not significant effect on feed force.

3.2. Main effects plot for F_Y

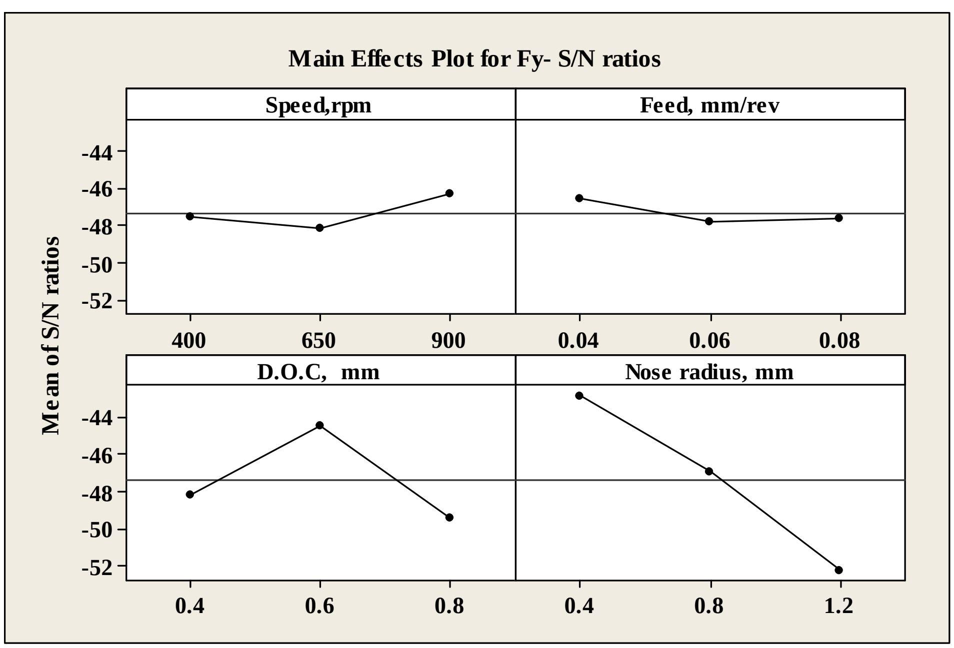

Figure 2 main effects plot for F_Y – S/N ratios

The slope of nose radius vs. mean of S/N ratio graph is largest, depth of cut vs. mean of S/N ratio graph possesses second largest slope so thrust force (Fy) is significantly affected by nose radius of the cutting tool and depth of cut but feed has not significant effect on thrust force.

3.3. Main effects plot for F_Z

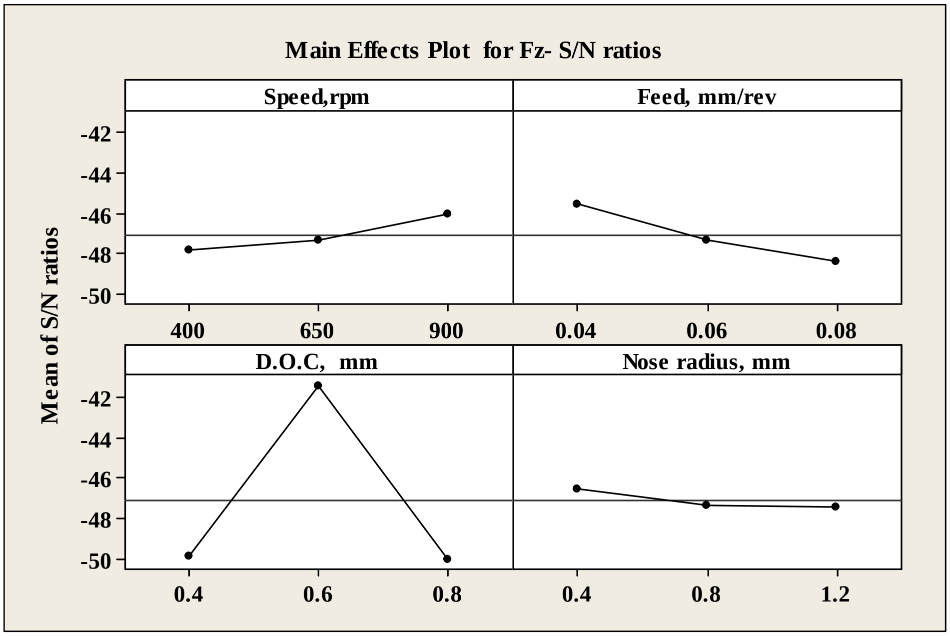

Figure 3 main effects plot for F_Z – S/N ratios

The slope of depth of cut vs. mean of S/N ratio graph is largest, feed vs. mean of S/N ratio graph possesses second largest slope. So tangential force (Fz) is significantly affected by depth of cut and feed but nose radius has not significant effect on tangential force.

4. CONCLUSIONS

This paper presents the findings of an experimental investigation of the effect of cutting speed, feed rate, depth of cut and nose radius on the feed force, thrust force, and tangential force in finish hard turning of AISI52100 (58 HRC) steel using PCBN cutting tools and following conclusions are drawn.

- Feed force: Depth of cut is the most significant factor and then Cutting speed also influenced the feed force
- Thrust force: Nose radius of cutting tool is mainly effect the thrust force that means larger nose radius gives more thrust force and Depth of cut also significant effect on thrust force
- Tangential force: Depth of cut is the most significant factor in the tangential force also and Feed rate also dominant factor in tangential force.

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